# Forces released by nonconventional bracket or ligature systems during alignment of buccally displaced teeth

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**Introduction:** The aim of this study was to analyze the forces released by 4 types of passive stainless steel self-ligating brackets and 2 nonconventional elastomeric ligature bracket systems compared with conventional elastomeric ligatures on stainless steel brackets during the alignment of buccally displaced teeth. **Methods:** A model consisting of 5 brackets (from second premolar through central incisor) was used to assess the forces released by the 7 bracket-ligature systems with 0.012- or 0.014-in superelastic wires with various amounts of buccal canine displacement (1.5-6.0 mm). The comparisons between the different types of bracket-wire-ligature systems were performed with 3-way ANOVA with the Tukey post-hoc test ($P < 0.05$). **Results:** For buccal misalignments of 1.5 and 3.0 mm, both low-friction and conventional systems released forces for bracket alignment ranging from about 30 to 160 g. For greater buccal displacements (4.5 and 6.0 mm), the low-friction systems produced a significant magnitude of force, but it dropped to 0 g for the conventional system. **Conclusions:** Nonconventional elastomeric ligature bracket systems produced levels of force for tooth movement that were similar to those generated by passive self-ligating brackets. (Am J Orthod Dentofacial Orthop 2009;136:316.e1-316.e6)

Self-ligating brackets (SLBs) have gained popularity among orthodontists in recent decades. SLBs can be classified into 2 main categories: those with a spring clip that presses against the archwire (active or interactive SLBs), and those whose self-ligating clip does not press against the archwire (passive SLBs). Passive SLBs have consistently shown lower friction than active SLBs, because of their use with undersized round archwires.[1,2] Significant reductions in friction have also been reported for nonconventional elastomeric ligatures on conventional brackets[3-5] and conventional elastomeric ligatures on specifically designed brackets.[6,7]

Classic in-vitro studies have aimed to measure friction with various amounts of tooth displacement.[8,9] However, static and kinetic frictions were evaluated solely by drawing the orthodontic archwire through a series of aligned or misaligned brackets. Recently, a new methodology was introduced to measure the magnitude of force available for orthodontic movement, with a more direct clinical meaning.[3] A specific testing device was proposed to recreate clinical conditions for the levelling and aligning phase of the straight-wire technique: ie, to study the forces available for alignment of vertically displaced teeth.[3,5] The tests were conducted with unconventional ligatures on conventional brackets with various amounts of misalignment of the canine bracket in a gingival direction with regard to the 4 remaining aligned brackets. No information about the forces available for alignment of horizontally displaced teeth (either in a lingual or buccal direction) has been provided yet.

The aim of this study, therefore, was to analyze the forces released by 4 types of passive stainless steel SLBs and 2 nonconventional elastomeric ligature-bracket systems compared with conventional elastomeric ligatures on conventional brackets during the alignment of buccally displaced teeth.

## MATERIAL AND METHODS

An experimental model consisting of 5 brackets (from the maxillary right second premolar through the right central incisor) was used to assess the forces released during the alignment of a buccally displaced canine. The following brackets were tested. The 4 types

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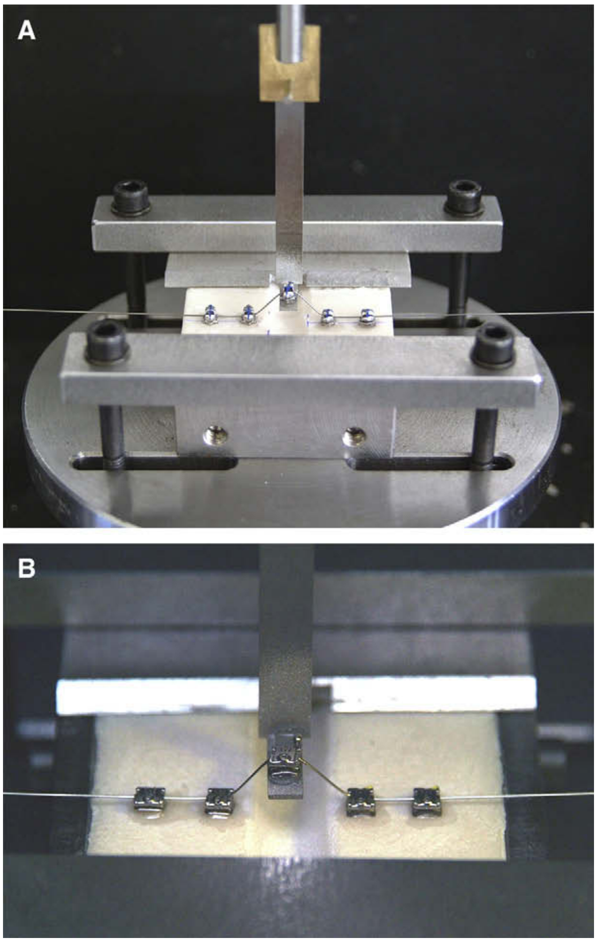


**Fig 1. A,** Experimental in-vitro model with buccal misalignment of the canine bracket (Opal); **B,** close-up view with a canine bracket (Carriere) welded to the movable bar.

of passive SLBs were Carriere (Ortho Organizers, Carlsbad, Calif), Damon 3 MX (SDS Ormco, Orange, Calif), SmartClip (3M Unitek, Monrovia, Calif), and Opal-M (Ultradent Products, South Jordan, Utah). The conventional stainless steel brackets were Logic Line (Leone Orthodontic Products, Sesto Fiorentino, Firenze, Italy) and Synergy (Rocky Mountain Orthodontics, Denver, Colo). All brackets had a 0.022-in slot. The interbracket distance was set at 8.5 mm. The brackets were bonded onto an acrylic block with light-cured orthodontic adhesive (Leone Orthodontic Products), with the exception of the canine bracket that was laser-welded to a moveable bar (Fig 1). This bar was connected to a testing machine (model 4301, Instron, Canton, Mass) crosshead. A groove in the acrylic block accommodated the bar when all brackets were aligned. A section of 0.0215 × 0.028-in stainless steel wire was used to align the brackets before they were fixed onto the acrylic block.

For the ligation systems on the other 2 brackets, either nonconventional elastomeric ligatures (Slide, Leone Orthodontic Products) or conventional elastomeric ligatures (silver minimodules, Leone Orthodontic Products) were applied on conventional stainless steel brackets. Specific elastomeric ligatures (Synergy low-friction white opaque ligatures, Rocky Mountain Orthodontics) with the zero-friction ligating option were used for the Synergy brackets. Thus, 7 bracket-ligature combinations were tested: 4 passive SLBs, Synergy brackets with Synergy low-friction ligatures, conventional stainless steel brackets with Slide ligatures, and conventional stainless steel brackets with conventional elastomeric ligatures.

Two sizes of round superelastic wires (Memoria, Leone Orthodontic Products) were tested: 0.012 and 0.014 in. The wires were austenitic nickel-titanium (NiTi) alloy with a temperature transitional range below room temperature.[10] When used, new elastomeric ligatures were placed in a conventional manner (figure-O pattern) immediately before each test run, to prevent ligature force decay. The testing machine with a load cell of 10 N was initially used to create 4 amounts of buccal displacement of the canine bracket (canine misalignment): 1.5, 3.0, 4.5, and 6.0 mm of misalignment. Then the moveable bar with the canine bracket was released, and this allowed recording the peak forces produced during 60 seconds of testing for the bracket-wire-ligature combinations. These forces could be considered the forces available for bracket alignment.

The forces released by each bracket-wire-ligature combination at the 4 amounts of horizontal canine misalignment were tested 20 times with new wires and ligatures on each occasion. A total of 1120 tests (160 tests for each bracket-wire-ligature combination) were carried out. All tests were performed under dry conditions and at room temperature (20°C ± 2°C).

### Statistical analysis

Three-way analysis of variance (ANOVA) was used to evaluate the effects of the variables (bracket-ligature combination, wire size, and amount of canine buccal misalignment) on the forces released during the experiment. The analysis of standardized residuals showed normal distribution of the data. Statistical between-group comparisons were performed with the Tukey post-hoc test. The level of significance was set at $P < 0.05$. All statistical computations were performed with statistical software (JMP 7, SAS Institute, Cary, NC).

## RESULTS

The 3-way ANOVA showed that the 3 variables (bracket-ligature combination, wire size, and amount of canine buccal misalignment) affected the results significantly (Table I). The results of the post-hoc statistical comparisons on the forces released by the different bracket-wire-ligature combinations with various amounts of canine buccal displacement are shown in Tables II and III.

With both the 0.012- and 0.014-in superelastic NiTi wires, all low-friction systems (passive SLBs, Synergy brackets with Synergy low-friction ligatures, and conventional stainless steel brackets with Slide ligatures) produced significantly greater forces for tooth movement than the conventional system (conventional elastomeric ligatures on conventional stainless steel brackets) at all amounts of canine buccal misalignment (Table III). The only exceptions were at 1.5 mm of canine displacement: the conventional system developed significantly greater force than the low-friction systems for both arch sizes, and, at 3.0 mm of canine misalignment, the force generated by the Slide ligatures on conventional brackets with the 0.012-in wire was not significantly different from the conventional system.

The low-friction systems showed a general tendency to increased magnitude of force released from 1.5 to 4.5 mm, with a relative decrease at 6.0 mm of canine displacement. From 3.0 through 6.0 mm of canine misalignment, the magnitude of force released by the conventional system decreased dramatically from 79.9 and 118.7 g at 3.0 mm of canine misalignment (with the 0.012- and 0.014-in wires, respectively) to 0 g at 4.5 and 6.0 mm of canine misalignment with both types of superelastic NiTi wires.

**Table I.** Three-way ANOVA showing the effects of the variables (wire size, bracket-ligature combination, and amount of canine buccal misalignment) on the forces released

| | | | |
|---|---|---|---|
| Summary of fit | | | |
| $R^2$ | | 0.986563 | |
| $R^2$ adjusted | | 0.985869 | |
| Root-mean-square error | | 4.789425 | |
| Mean of response | | 90.07556 | |
| Observations | | 1120 | |
| ANOVA | | | |
| Source | Sum of squares | Mean square | F ratio |
| Model | 1791995.3 | 32581.7 | 1420.390 |
| Error | 24406.7 | 22.9 | *P* |
| Total | 1816402.0 | | <0.0001 |
| Effect tests | | | |
| Source | Sum of squares | F ratio | *P* |
| Wire size (WS) | 278462.73 | 12139.49 | <0.0001 |
| Bracket-ligature combination (B-L) | 329483.69 | 2393.955 | <0.0001 |
| Amount of canine misalignment (CM) | 475589.18 | 6911.050 | <0.0001 |
| WS*B-L | 15231.96 | 110.6720 | <0.0001 |
| Summary of fit | | | |
| WS*CM | 33391.71 | 485.2335 | <0.0001 |
| B-L*CM | 618645.26 | 1498.313 | <0.0001 |
| WS*B/L*CM | 41190.77 | 99.7610 | <0.0001 |

## DISCUSSION

We evaluated in vitro the forces released by superelastic NiTi wires during alignment of a buccally displaced tooth with 6 low-friction systems (4 passive SLBs, Synergy brackets with Synergy low-friction ligatures, and conventional stainless steel brackets with Slide ligatures) vs a conventional system (conventional elastomeric ligatures on conventional stainless steel brackets).

The magnitude of force released by the low-friction and conventional systems with the 0.012-in wire was smaller than with the 0.014-in wire. This confirmed the findings of a previous similar in-vitro study on the effects of tooth misalignment in an apical position.[5] The bracket-ligature combination also affected the outcomes significantly. Low-friction combinations produced greater forces than the conventional combination, with the exception of the 1.5-mm canine buccal displacement. For this amount of displacement, the conventional system actually produced greater forces for tooth movement than the low-friction systems.

Along with the increase in the amount of buccal tooth displacement, significant differences between low-friction and conventional systems became exaggerated: at 4.5 and 6.0 mm of displacement, the magnitude of force released by the conventional system was 0 g, whereas in most instances it was over 100 g for the low-friction combinations. With increased buccal misalignment, the force exerted on the wire by the conventional elastomeric ligatures of the adjacent teeth tends to counteract the spring-back force of the wire available for tooth alignment. Previous in-vitro studies had already indicated that a null magnitude of force for alignment is released by the conventional system when misalignment (apical) either equals or is greater than 4.5 mm.[3,5] Moreover, in this study, in agreement with a previous one,[5] we demonstrated that nonconventional elastomeric ligature-bracket systems (Synergy brackets with Synergy low-friction ligatures, and conventional stainless steel brackets with Slide ligatures) produced significant forces for tooth movement; thus, these systems might be valid alternatives to passive SLBs during leveling and aligning of displaced teeth.

In addition to the assessment of the outcomes based on statistical significance, the data reported here should be interpreted also in terms of clinical consequences. In

**Table II.** Statistical comparisons of the forces (least squared mean in grams) released by the different combinations of the 3 variables

| *Variables** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | *Least squares mean* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,2,1 | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | 158.3441 |
| 1,1,1 | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | 157.1613 |
| 1,3,1 | | B | | | | | | | | | | | | | | | | | | | | | | | | | | | 148.4734 |
| 1,0,2 | | B | | | | | | | | | | | | | | | | | | | | | | | | | | | 146.3066 |
| 1,5,2 | | B | | | | | | | | | | | | | | | | | | | | | | | | | | | 145.8324 |
| 1,0,1 | | | C | | | | | | | | | | | | | | | | | | | | | | | | | | 139.0004 |
| 1,4,2 | | | C | D | | | | | | | | | | | | | | | | | | | | | | | | | 136.5531 |
| 1,5,1 | | | | D | E | | | | | | | | | | | | | | | | | | | | | | | | 131.4495 |
| 1,4,1 | | | | | E | F | | | | | | | | | | | | | | | | | | | | | | | 127.6460 |
| 1,3,2 | | | | | E | F | G | | | | | | | | | | | | | | | | | | | | | | 126.7742 |
| 1,1,2 | | | | | | F | G | H | | | | | | | | | | | | | | | | | | | | | 123.5825 |
| 1,2,2 | | | | | | F | G | H | | | | | | | | | | | | | | | | | | | | | 122.6087 |
| 1,4,3 | | | | | | | G | H | I | | | | | | | | | | | | | | | | | | | | 121.1964 |
| 1,6,0 | | | | | | | G | H | I | | | | | | | | | | | | | | | | | | | | 121.0843 |
| 1,6,1 | | | | | | | | H | I | J | | | | | | | | | | | | | | | | | | | 118.6676 |
| 1,0,3 | | | | | | | | H | I | J | | | | | | | | | | | | | | | | | | | 117.8671 |
| 1,3,3 | | | | | | | | | I | J | K | | | | | | | | | | | | | | | | | | 115.9932 |
| 0,3,2 | | | | | | | | | | J | K | | | | | | | | | | | | | | | | | | 114.3903 |
| 0,3,3 | | | | | | | | | | J | K | | | | | | | | | | | | | | | | | | 113.1255 |
| 1,5,3 | | | | | | | | | | | K | L | | | | | | | | | | | | | | | | | 110.7037 |
| 1,1,3 | | | | | | | | | | | | L | M | | | | | | | | | | | | | | | | 105.7123 |
| 1,2,3 | | | | | | | | | | | | L | M | N | | | | | | | | | | | | | | | 104.8812 |
| 0,0,2 | | | | | | | | | | | | L | M | N | | | | | | | | | | | | | | | 104.8275 |
| 0,2,2 | | | | | | | | | | | | L | M | N | | | | | | | | | | | | | | | 104.6110 |
| 0,4,2 | | | | | | | | | | | | | M | N | | | | | | | | | | | | | | | 102.0669 |
| 0,1,2 | | | | | | | | | | | | | M | N | O | | | | | | | | | | | | | | 100.8585 |
| 0,2,1 | | | | | | | | | | | | | | N | O | | | | | | | | | | | | | | 99.3698 |
| 0,3,1 | | | | | | | | | | | | | | | O | P | | | | | | | | | | | | | 95.7753 |
| 0,0,1 | | | | | | | | | | | | | | | O | P | Q | | | | | | | | | | | | 95.0156 |
| 0,4,1 | | | | | | | | | | | | | | | | P | Q | R | | | | | | | | | | | 89.9477 |
| 0,5,2 | | | | | | | | | | | | | | | | | Q | R | | | | | | | | | | | 89.5042 |
| 0,1,1 | | | | | | | | | | | | | | | | | | R | | | | | | | | | | | 88.2754 |
| 0,4,3 | | | | | | | | | | | | | | | | | | R | S | | | | | | | | | | 86.9804 |
| 0,1,3 | | | | | | | | | | | | | | | | | | | S | T | | | | | | | | | 80.9030 |
| 0,0,3 | | | | | | | | | | | | | | | | | | | | T | | | | | | | | | 80.1892 |
| 0,6,1 | | | | | | | | | | | | | | | | | | | | T | | | | | | | | | 79.9037 |
| 0,5,1 | | | | | | | | | | | | | | | | | | | | T | | | | | | | | | 79.6437 |
| 0,6,0 | | | | | | | | | | | | | | | | | | | | T | U | | | | | | | | 76.3449 |
| 0,5,3 | | | | | | | | | | | | | | | | | | | | T | U | V | | | | | | | 74.9174 |
| 1,3,0 | | | | | | | | | | | | | | | | | | | | | U | V | | | | | | | 72.4497 |
| 1,1,0 | | | | | | | | | | | | | | | | | | | | | U | V | | | | | | | 72.0112 |
| 0,2,3 | | | | | | | | | | | | | | | | | | | | | | V | | | | | | | 69.8800 |
| 1,2,0 | | | | | | | | | | | | | | | | | | | | | | V | | | | | | | 69.0592 |
| 1,0,0 | | | | | | | | | | | | | | | | | | | | | | | W | | | | | | 60.7027 |
| 0,0,0 | | | | | | | | | | | | | | | | | | | | | | | W | X | | | | | 57.7150 |
| 1,5,0 | | | | | | | | | | | | | | | | | | | | | | | W | X | Y | | | | 55.7215 |
| 1,4,0 | | | | | | | | | | | | | | | | | | | | | | | | X | Y | | | | 53.8351 |
| 0,3,0 | | | | | | | | | | | | | | | | | | | | | | | | | Y | | | | 50.4089 |
| 0,2,0 | | | | | | | | | | | | | | | | | | | | | | | | | Y | | | | 50.3528 |
| 0,4,0 | | | | | | | | | | | | | | | | | | | | | | | | | | Z | | | 34.5321 |
| 0,1,0 | | | | | | | | | | | | | | | | | | | | | | | | | | Z | | | 33.7623 |
| 0,5,0 | | | | | | | | | | | | | | | | | | | | | | | | | | | [ | | 27.3127 |
| 1,6,3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | \ | –3.908e-14 |
| 0,6,3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | \ | –5.329e-14 |
| 0,6,2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | \ | –1.03e-13 |
| 1,6,2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | \ | –1.172e-13 |

**Left number* is wire size: *0,* 0.012 in, and *1,* 0.014 in. *Middle number* is bracket-ligature combination: *0,* Carriere; *1,* Damon 3MX; *2,* SmartClip; *3,* Synergy brackets with Synergy low-friction ligatures; *4,* Opal; *5,* Logic Line brackets with Slide ligatures; and *6,* Logic Line brackets with conventional elastomeric ligatures. *Right number* is amount of canine misalignment: *0,* 1.5 mm; *1,* 3.0 mm; *2,* 4.5 mm; and *3,* 6.0 mm. Combinations that are not connected by the same letter or character are significantly different (Tukey test, $P < 0.05$).

**Table III.** Comparisons (Tukey test, $P < 0.05$) between the forces (grams) released by the low-friction systems (Carriere, Damon, SmartClip, Opal, Synergy + SLL, Logic + Slide) with respect to the conventional system (Logic + CEL) with different wire sizes and amounts of canine misalignment

| | *Carriere (1)* | | *Damon (2)* | | *SmartClip (3)* | | *Opal (4)* | | *Synergy + SLL (5)* | | *Logic + Slide (6)* | | *Logic + CEL (7)* | | *Statistically significant comparisons vs (7)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* | |
| 0.012 in SENT 1.5 mm CM | 57.7 | 5.0 | 33.8 | 0.7 | 50.4 | 1.3 | 50.4 | 1.3 | 34.5 | 1.6 | 27.3 | 0.8 | 76.3 | 3.8 | 1,2,3,4,5,6 |
| 0.012 in SENT 3.0 mm CM | 95.0 | 7.9 | 88.3 | 1.4 | 99.4 | 5.8 | 95.8 | 4.7 | 89.9 | 1.4 | 79.6 | 2.0 | 79.9 | 3.2 | 1,2,3,4,5 |
| 0.012 in SENT 4.5 mm CM | 104.8 | 6.2 | 100.9 | 8.0 | 104.6 | 5.1 | 114.4 | 6.9 | 102.1 | 2.4 | 89.5 | 3.0 | 0.0 | 0.0 | 1,2,3,4,5,6 |
| 0.012 in SENT 6.0 mm CM | 80.2 | 5.8 | 80.9 | 7.7 | 69.9 | 4.7 | 113.1 | 6.7 | 87.0 | 6.7 | 74.9 | 3.6 | 0.0 | 0.0 | 1,2,3,4,5,6 |
| 0.014 in SENT 1.5 mm CM | 60.7 | 2.4 | 72.0 | 4.3 | 69.1 | 5.8 | 72.4 | 5.9 | 53.8 | 1.0 | 55.7 | 2.1 | 121.1 | 0.7 | 1,2,3,4,5,6 |
| 0.014 in SENT 3.0 mm CM | 139.0 | 2.0 | 157.2 | 4.1 | 158.3 | 4.5 | 148.5 | 2.0 | 127.6 | 2.9 | 131.4 | 2.6 | 118.7 | 2.9 | 1,2,3,4,5,6 |
| 0.014 in SENT 4.5 mm CM | 146.3 | 6.4 | 123.6 | 8.2 | 122.6 | 7.5 | 126.8 | 7.4 | 136.6 | 2.9 | 145.8 | 4.9 | 0.0 | 0.0 | 1,2,3,4,5,6 |
| 0.014 in SENT 6.0 mm CM | 117.9 | 5.5 | 105.7 | 4.5 | 104.9 | 4.4 | 116.0 | 9.9 | 121.2 | 4.0 | 110.7 | 9.4 | 0.0 | 0.0 | 1,2,3,4,5,6 |

*SENT,* Superelastic NiTi; *CM,* canine misalignment; *SLL,* Synergy low-friction ligatures; *CEL,* conventional elastomeric ligatures.

this context, they can be compared with observations on the differential effects of low-friction vs conventional systems as derived from clinical observations in vivo.[11]

For buccal misalignments of 1.5 and 3.0 mm, all systems (both low-friction and conventional) appeared to be effective in releasing forces for tooth movement from about 30 to 160 g. Conventional systems release greater forces at 1.5 mm of canine misalignment, and the low-friction combinations release significantly greater forces at 3.0 mm of displacement (Fig 2). These findings are similar to those of a recent randomized controlled trial of patients with mandibular incisor crowding.[11] The authors found no significant difference between low-friction and conventional systems in the alignment of the dental arches. The total irregularity index of the mandibular incisors was between 3.0 and 12.0 mm (this means, on average, from <1 mm to <3 mm of buccolingual misalignment per tooth in relation to the neighboring teeth in the crowded area).

When the amount of buccal displacement became larger (4.5 and 6.0 mm), the low-friction systems released a significant magnitude of force for tooth movement, but this magnitude dropped to 0 g for the conventional bracket-ligature combination (Fig 2). However, in this study, we did not evaluate the behavior of bracket-ligature systems with time. The decay of the conventional elastomeric ligatures because of their permanence in the oral environment, along with changes in temperature, saliva, toothbrushing, and so on, might considerably affect the forces released by the conventional systems with time. Moreover, our findings showed that the various low-friction systems produced the greatest magnitude of forces for tooth movement at 3.0 and 4.5 mm of buccal

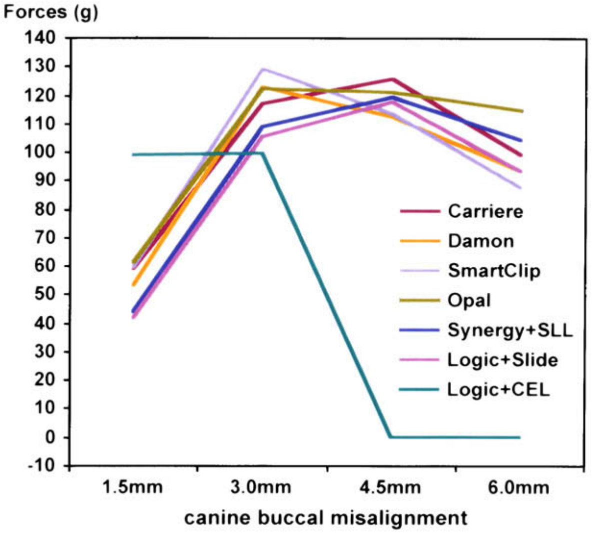


**Fig 2.** Interaction profile chart showing the forces released by the various bracket-ligature combinations at the 4 amounts of canine misalignment. The data represent the average forces released by 0.012- and 0.014-in NiTi wires.

misalignment, but the force tended to decrease at 6.0 mm of displacement (Fig 2).

We found no clinically meaningful difference in terms of the magnitude of forces generated by the various passive SLBs or low-friction ligature systems (Fig 2). With the same wire and the same level of tooth misalignment, all low-friction systems behaved similarly, and they consistently produced forces for orthodontic movement.

## CONCLUSIONS

1. For buccal misalignments of 1.5 and 3.0 mm, both low-friction and conventional systems released forces for tooth movement from about 30 to 160 g. The conventional system released significantly greater forces at 1.5 mm of misalignment, whereas the low-friction combinations released significantly greater forces at 3.0 mm of displacement.
2. With large amounts of buccal tooth displacement (4.5 and 6.0 mm), the low-friction systems had significant magnitudes of force for tooth movement, but this magnitude was null for the conventional bracket-ligature combination.
3. Nonconventional elastomeric ligature-bracket systems (Synergy brackets with Synergy low-friction ligatures, and conventional stainless steel brackets with Slide ligatures) produced forces for tooth movement that were similar to those generated by passive SLBs.

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